

Electroplated Copper Filling of Through Holes on Varying Substrate Thickness

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ABSTRACT

This paper discusses a through-hole copper filling process for application to high density interconnect constructions and IC substrates. The process consists of two acid copper plating cycles. The first cycle uses periodic pulse reverse electroplating to form a bridge in the middle of the hole, followed by direct current electroplating to fill the resultant vias formed during the bridge cycle. This process can provide defect-free filled holes with total plated copper on the surface below 25 μm , with dimples less than 5 μm for boards with core thickness of 0.2 mm and 0.25 mm. This process was designed to be deployed in vertical continuous plating equipment, (VCP), thus reducing capital equipment costs as compared to horizontal conveyerized electroplaters.

The chemical components, copper, acid, and additive, for the periodic pulse reverse plating cycle, are optimized via experimental conditions selected from DOE (design of experiments) software. Critical parameters are identified and the impact on cavity formation during the bridging step is quantified. The additive and copper concentrations play key roles in reducing defects during bridge formation and on the resultant via formation.

A high performance via-filling process is used to fill the formed vias, with less than 5 μm dimple depth, while depositing approximately 12 microns on the surface. The thin surface copper enables fine line resolution without the need for planarization or grinding. The mechanical properties of the plated deposit meet or exceed all IPC standards.

This process is applicable to both laser-drilled X shape through holes and mechanically-drilled straight holes. Laser-drilled through holes are bridged faster than mechanically drilled holes. However, mechanically drilled holes show a lower tendency for drilling induced defects, especially at a hole diameter of 0.1mm. This process has shown capability to fill through-holes in thicker cores of 0.4 mm to 0.8 mm, where further investigation continues.

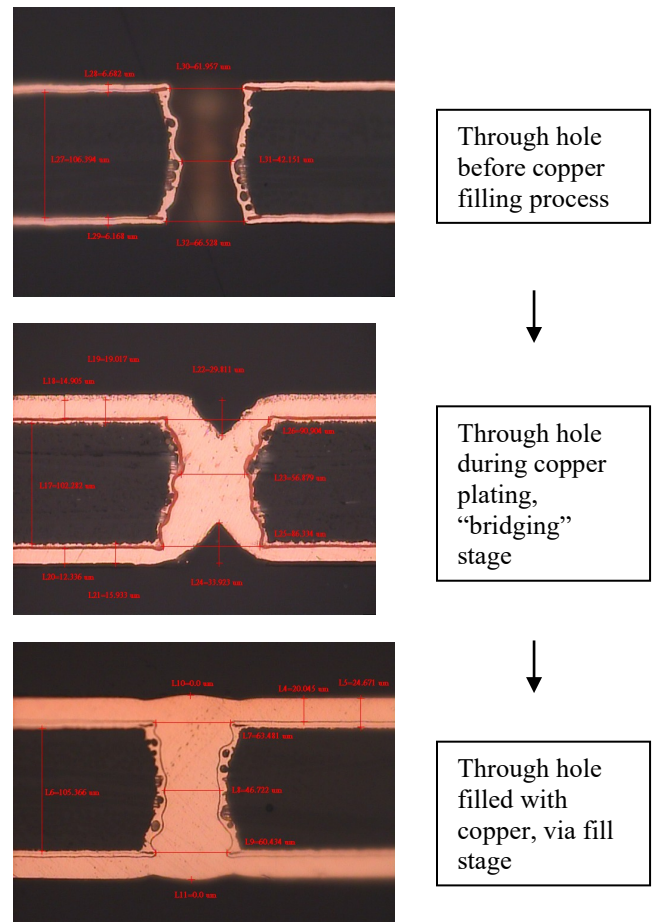
INTRODUCTION

Resin or paste plugging of through holes in cores has been part of build up technology, especially in IC substrate for many years. However, increasing circuit density and stacked via constructions coupled with higher power devices have added an extra dimension of thermal management. Solid copper filling of these through holes offers many advantages, such as reducing the CTE mismatch, providing a stable platform for stacking microvias, and offering thermal management properties for high power devices. New technologies started to develop in order to completely fill through holes and vias in build-up core layers in HDI and IC substrates with solid copper. One of the approaches for filling through holes with copper is via DC plating technology, for a thin core board with laser-

drilled X shaped through holes as shown below, in Figure 1. The plated copper on the surface can be controlled below 25 μm , with core thickness around 100 μm , and hole diameters around 100 μm , with 50-70 μm diameters in the middle of the laser-drilled X shape through hole.

The filling process consists of two stages. During the initial stage, copper is preferentially deposited in the middle of the through holes until the copper plating in the center of the hole meets, resulting in the formation of two blind microvias. This stage is called “bridging”.

FIGURE 1. COPPER FILLING STAGES VIA DC PLATING TECHNOLOGY



The second stage consists of filling, the resultant double blind vias. A single chemistry and one step plating process is ideal for filling through holes with solid copper. However, DC plating is limited by the thickness of the substrate. Once the substrate thickness is above

200 μm , the propensity for inclusions/cavities grows and the plated surface copper thickness increases beyond the 25 μm limit. Higher incidence of cavities may reduce reliability while the increased surface copper plating thickness reduces the ability to resolve fine line and space requirements. These limitations are exacerbated for the boards with mechanical drilled through holes.

TWO STEP THROUGH HOLE FILL TECHNOLOGY

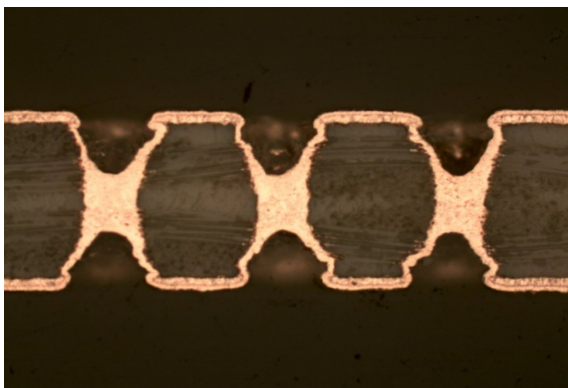
The two-stage concept is adopted into two-step plating. The first step consists of “bridging” with periodic pulse reverse plating, then filling the resultant double blind via by a via-fill plating process. The combined processes offer defect-free solid copper filling technology for boards with through holes, both laser drilled, and mechanical drilled.

Through holes are processed through standard primary metallization processes, including permanganate desmear or plasma desmear, electroless copper plating, or a direct metallization process, such as Blackhole, to make the holes conductive. To obtain a conductive copper layer inside the through hole, flash plating can be used to make sure the through holes have good conductivity across the entire hole wall. The pre-plate chemistries and process cycles were not changed to accommodate the acid copper plating process.

Bridging Step by Periodic Pulse Reverse Plating, Via Formation

Periodic pulse reverse plating is a widely used electrolytic copper plating process. Over the past decade, this technology has gained widespread adaptation in the conformal plating of high aspect ratio through holes. The practice of periodic pulse reverse plating has continued to develop. New rectifiers and software now offer greater flexibility for wave forms, including asynchronous pulse wave formations. These waveforms accelerate the plating rate in the center of the through holes, i.e. up to 5 times the rate compared to conventional pulse waves. The plated copper merges together in the middle of the hole to form two opposing vias as shown in Figure 2. This process is called the “bridging” step. A standard vertical plating cell was designed to achieve this new type of plating capability inside the through holes. A vertical plating cell, installed with insoluble IrO mesh anodes, offers the widest operating range of current density plating for bridging through holes. Additional considerations for the vertical plating cell include anode shielding, anode/cathode spacing, area ratio, panel agitation, solution movement, solution flow rate, and the panel clamping system.

FIGURE 2. CROSS-SECTION AFTER BRIDGING STEP



After the bridging step, the two opposing vias are filled with an efficient via fill acid copper plating solution to complete the through hole copper filling process as shown in Figure 3.

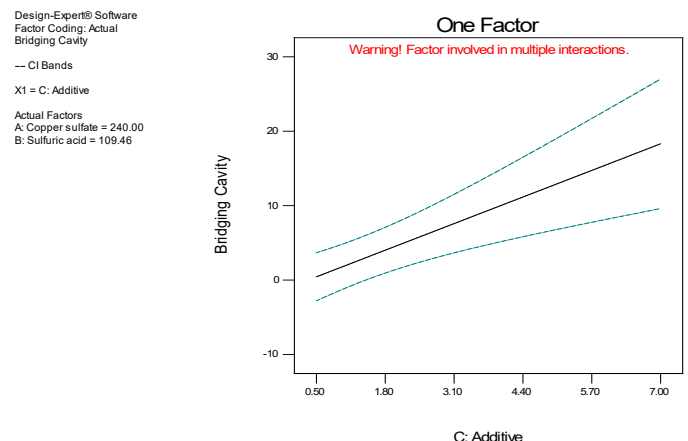
FIGURE 3. CROSS-SECTION AFTER BRIDGING AND VIA FILLING STEP



Chemistry for Bridging Step

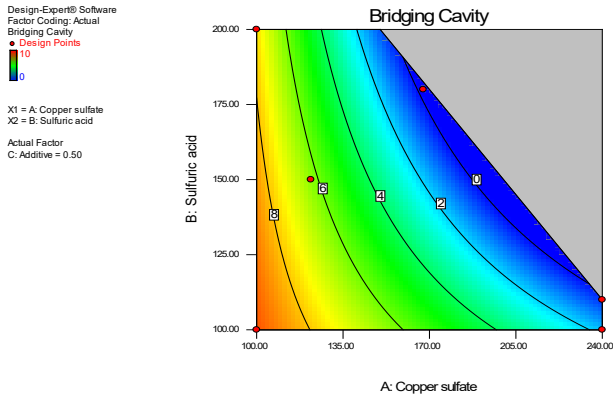
The chemistry for the periodic pulse reverse acid copper plating process, used during bridge step, is iSYS ELECTROPLATE PPR THF. This process contains a specifically designed organic additive system for pulse plating applications. The electrolyte components, copper sulfate, sulfuric acid, and chloride ion, are typical of standard acid copper plating solutions. To study the interaction among the chemical components, the concentrations of copper sulfate, and sulfuric acid, as well the additive concentration, experimental conditions were selected from DOE (design of experiments) software, to achieve good hole bridging/filling performance, and cavity-free plating in the middle of the through holes. As a DOE constraint, the combined copper sulfate and sulfuric acid concentrations were kept below 350 g/L, to keep the plating solution from forming copper sulfate crystals. The boards with through-holes used for the DOE were laser-drilled X hole boards with a core thickness of 200 μm , and a hole diameter of 100 μm . After the bridging step, 10 through holes were inspected, for each tested condition, by cross-section, to determine if any cavities were present in the copper filled through holes, as shown in Figure 3 above.

CHART 1: DOE RESULTS ON THE EFFECT OF ADDITIVE CONCENTRATION ON CAVITY FORMATION DURING THE BRIDGING STEP



DOE experiments indicated that additive and copper concentrations play important roles in obtaining cavity-free copper plating during the bridging step. It is essential to have lower additive and higher copper sulfate concentration, as shown in the Chart 1 and 2. One of the best combinations of each component is copper sulfate at 240 g/L, sulfuric acid at 110 g/L, and additive at 0.5 ml/L.

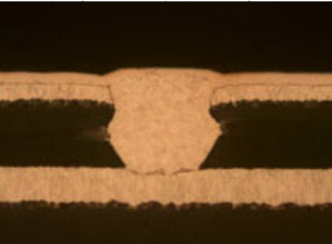
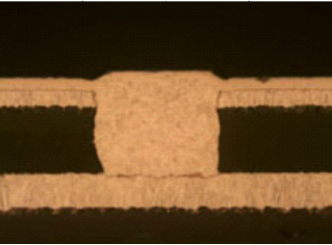
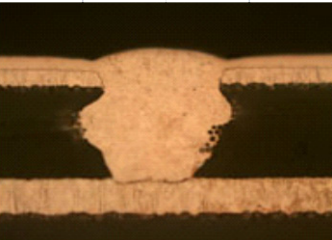
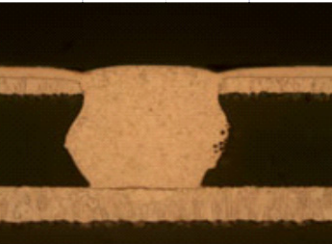
CHART 2. DOE RESULTS ON THE NUMBER OF CAVITIES, INFLUENCED BY COPPER SULFATE AND SULFURIC ACID CONCENTRATIONS, WHEN THE ADDITIVE CONCENTRATION WAS AT 0.5 ML/L



Via Filling Step by DC Plating

Electrolytic copper microvia filling technology has been widely used in manufacturing HDI and IC packaging substrates. A new copper plating process, MACUSPEC AVF 300, is used to fill the resultant blind vias after the bridging step. MACUSPEC AVF 300 offers thin plated copper thickness on the panel surface, with minimal dimple depth, as demonstrated in Figure 4 below.

FIGURE 4. MACUSPEC AVF 300 VIA FILLING CAPABILITY (UNIT IN μM)

75x75	Dimple	Fill ratio	Surface	100x75	Dimple	Fill ratio	Surface
	0.0	100.0%	9.6		0.0	100.0%	10.8
							
100x100	Dimple	Fill ratio	Surface	125x100	Dimple	Fill ratio	Surface
	0.0	100.0%	11.2		0.0	100.0%	10.4
							

The combined plating processes of iSYS ELECTROPLATE PPR THF bridging and MACUSPEC AVF 300 via filling steps, offer copper filling technology on thicker boards with different diameter through holes.

Solid copper through hole filling, with boards of various core thickness

This hole filling technology with solid copper can be applied to boards with the varying core thickness and hole geometries.

- Boards with a core thickness of 200 μm , containing laser drilled through holes with a 100 μm diameter at the surface, and 50-70 μm diameter in the middle of the hole.

Laser-drilled X through holes require less bridge plating time than mechanically drilled straight holes. Complete bridging of laser-drilled X through holes is achieved in approximately 30 minutes with a core thickness of 200 μm . When the laser-drilled X holes showed inconsistency in the diameter of the middle of hole, as shown in the Figure 3, cavity-free copper filled through holes can still be obtained. The plating time for via filling was about 50 minutes. Total plated copper on the surface was approximately 20 μm , as shown in Figure 3.

- Boards with core thickness of 200 μm and 250 μm , containing mechanically drilled 100 μm diameter holes

The plating time for mechanically drilled through holes is approximately 60 minutes for the bridging step, and approximately 50 minutes for the via filling step. Plated surface copper is about 25 μm , as shown in Figures 5 and 6.

FIGURE 5. MECHANICAL DRILLED THROUGH HOLE, CORE THICKNESS OF 200 μM

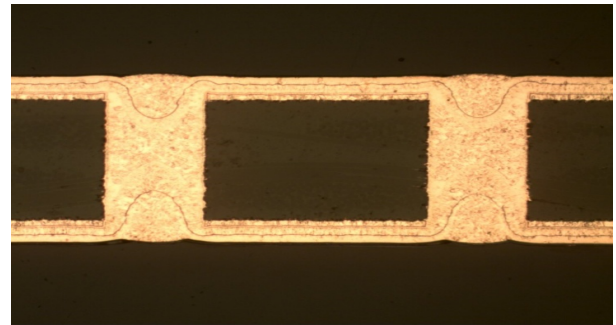
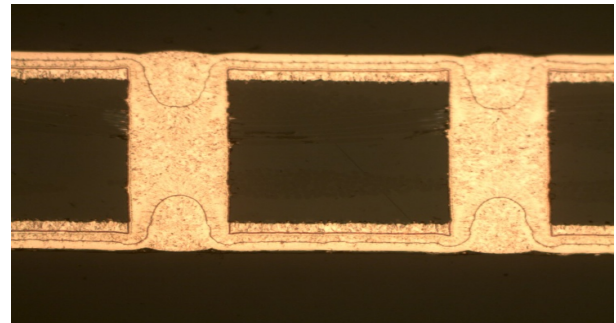


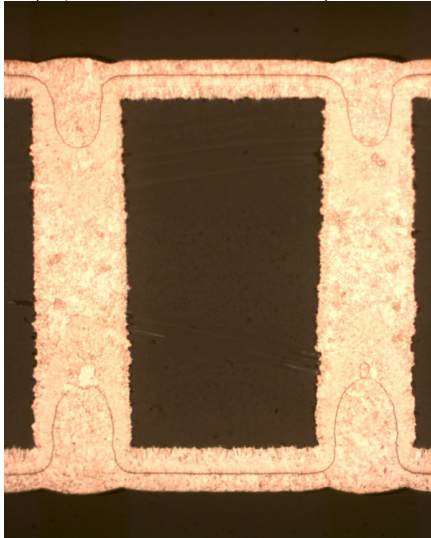
FIGURE 6. MECHANICAL DRILLED THROUGH HOLE, CORE THICKNESS OF 250 μM



- Boards with core thickness of 400 μm , containing mechanically drilled 100 μm diameter holes

Longer bridge plating time is required for panels with a 400 μm core thickness, with mechanically drilled 100 μm diameter holes. The plating time on the bridging step was approximately 120 minutes, while the via filling plating time remained at 50 minutes. Plated surface copper thickness is approximately 35 μm total, as seen in Figure 7.

FIGURE 7. MECHANICAL DRILLED THROUGH HOLE, CORE THICKNESS OF 400 μm , HOLE DIAMETER AT 100 μm



For panels at 400 μm core thickness, it took longer time to fill the resultant vias. This leads to more plated copper thickness on the surface of the panel.

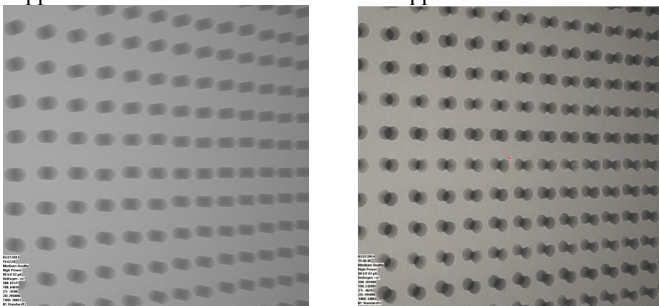
- Boards with core thickness of 800 μm , containing mechanically drilled through holes

It becomes challenging to bridge panels with a core thickness of 800 μm . In holes with diameters below 300 μm , cavities were observed.

X-ray Inspection

Most of the evaluation was done under microscope with cross-sections. X-ray inspection was used to inspect boards with a core thickness of 200 μm , with both mechanically drilled through holes and laser-drilled X through holes. X-ray inspection, after the two step plating process, showed that the copper plating in the through holes were defect-free, as seen in Figure 8.

FIGURE 8. X-RAY IMAGE ON THE BOARD WITH THICKNESS OF 200 μm
Copper filled mechanical drilled hole Copper filled laser drilled hole



Physical Properties

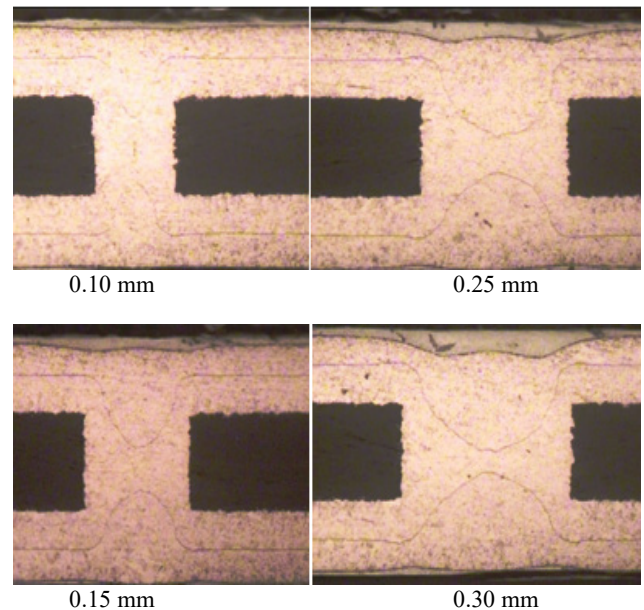
The physical properties of the deposit are critical to insure acceptable quality of the finished board. Tensile strength and percent elongation were measured by an Instron model 1011 pull tester, with the copper plated in bridging bath, and the via fill bath, as well. The results are listed in Table 1.

TABLE 1. RESULTS ON ELONGATION AND TENSILE STRENGTH

Plating cycle	Sample #	Plated copper thickness (mil)	Break Force (lbf)	Weight (g)	Elongation (%)	Tensile Strength (PSI)
Copper plated with bridging plus via fill process	1	2.82	62.75	0.9726	21.92	47098.0
	2	3.23	72.83	1.1146	21.19	47699.5
	3	2.71	60.21	0.9348	20.79	47018.9
	4	2.87	62.89	0.9901	19.46	46368.8
	5	3.05	68.12	1.0510	22.47	47314.6
	Mean	3.94	65.36	1.0126	21.17	47100.0

A board with a core thickness of 250 μm , with hole diameters between 100 to 300 μm , was bridged and filled with copper. This panel was subjected to thermal stress evaluation, according to IPC TM-650 2.6.8 6X solder floats for 10 seconds at 288 $^{\circ}\text{C}$. The deposit integrity was excellent, as neither crack nor separation was observed in any of the tested through holes, as seen in Figure 9.

FIGURE 9. CROSS-SECTION AFTER 6 X OF SOLDER SHOCK



CONCLUSIONS

A through-hole copper filling technology for application to high density interconnect constructions and IC substrates was demonstrated. The process consists of two acid copper plating cycles. The first cycle is periodic pulse reverse electroplating to form a bridge in the middle of the hole, followed by direct current electroplating to fill the resultant double vias formed during the bridge cycle. This process can provide defect-free filled through holes with solid copper. The mechanical properties of the plated deposit meet or exceed all IPC standards.